Liquid Argon TPCs

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WORKSHOP ON FUNDAMENTAL PHYSICS AT THE SECOND TARGET STATION

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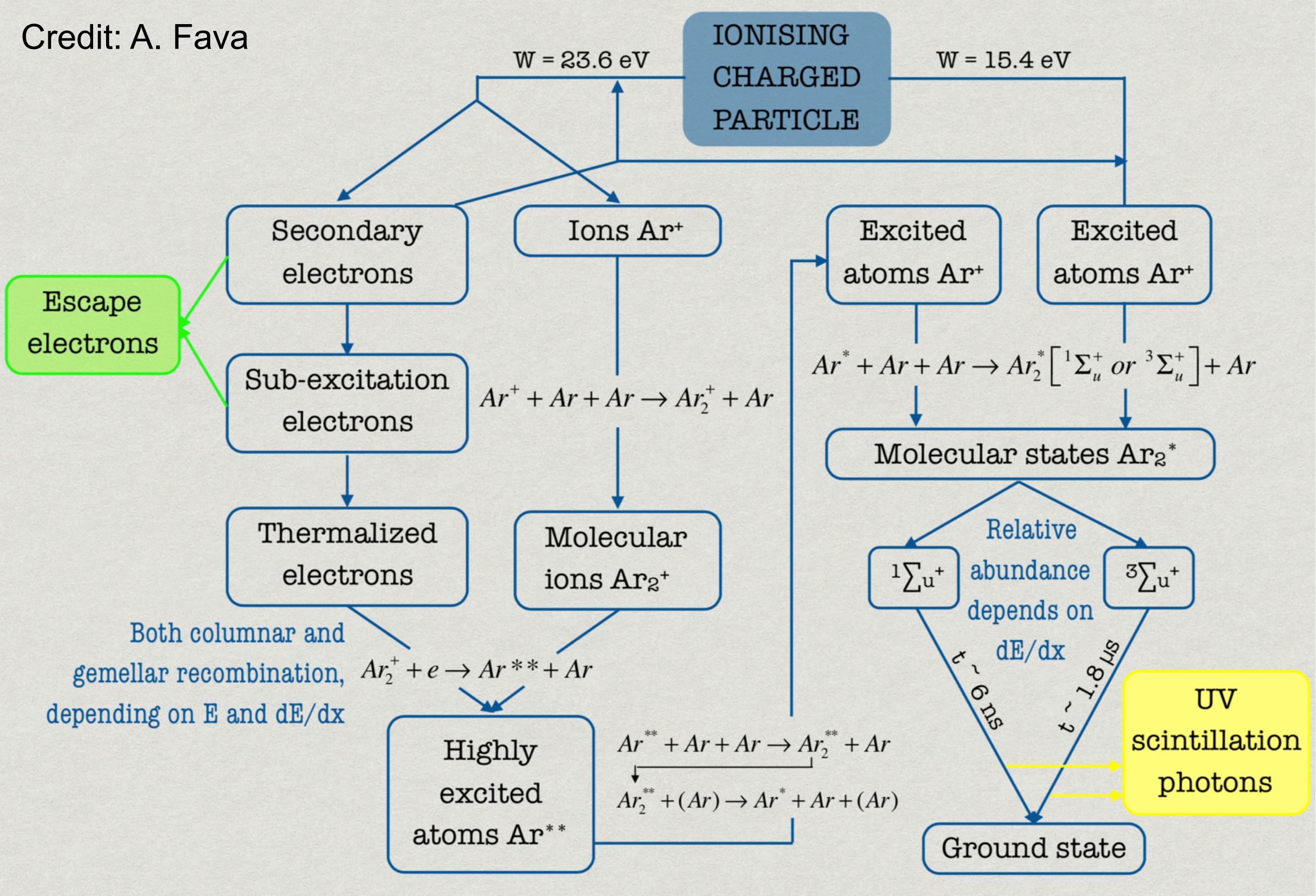
Two detection opportunities for interaction of charged particles with Ar

- **Ionization electrons**
  - Ionization potential: ~24 eV needed per electron/ion pair created
- **Scintillation light**
  - 128nm VUV, ~40 photons per keV (depends on E field, particle type, and argon purity)
  - Early & late light components
    - Dark matter detectors use ratio for discrimination of electron-like from nuclear-recoil-like events

This talk will mostly discuss needs for ionization detection

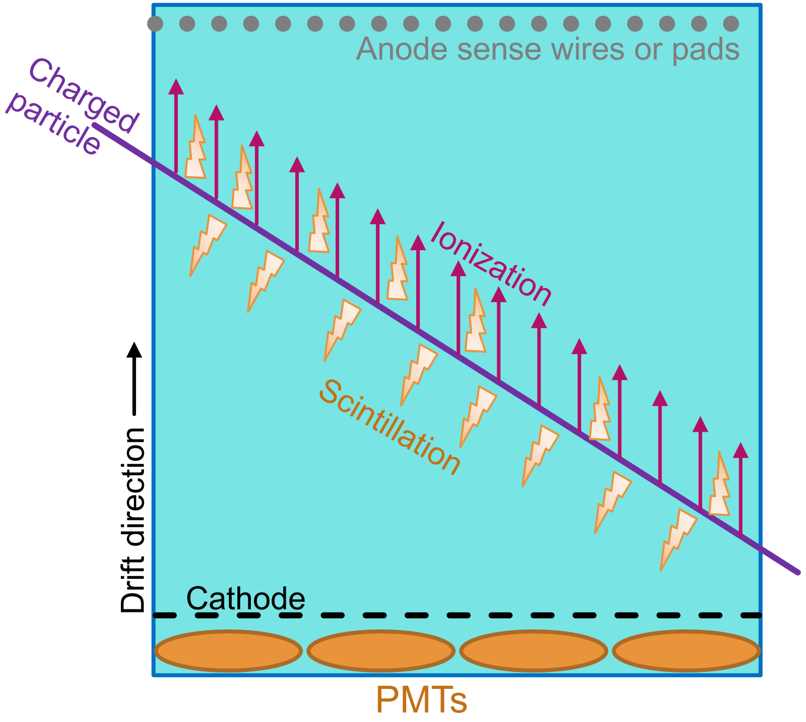


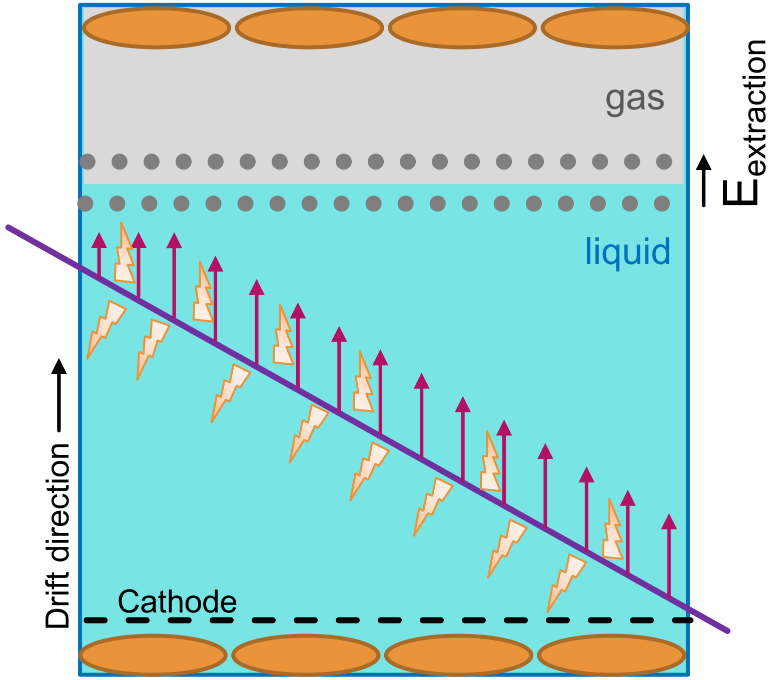
Single vs. dual phase TPCs

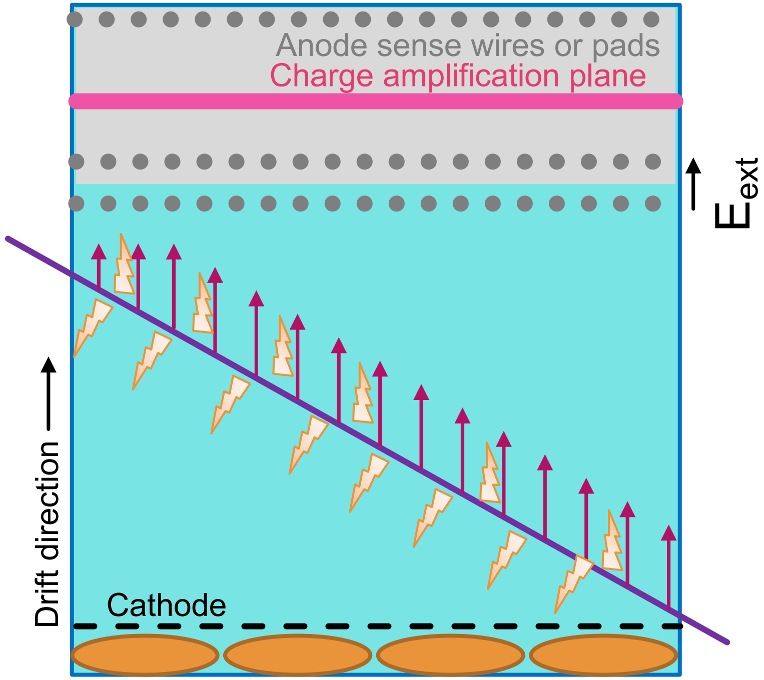
Single phase
Light collected by PMTs
Ionization charge detected at wires/pads

“Light-based” dual phase
Light and charge created in primary interaction
Also detect secondary light created when ionization charge is extracted into gas phase

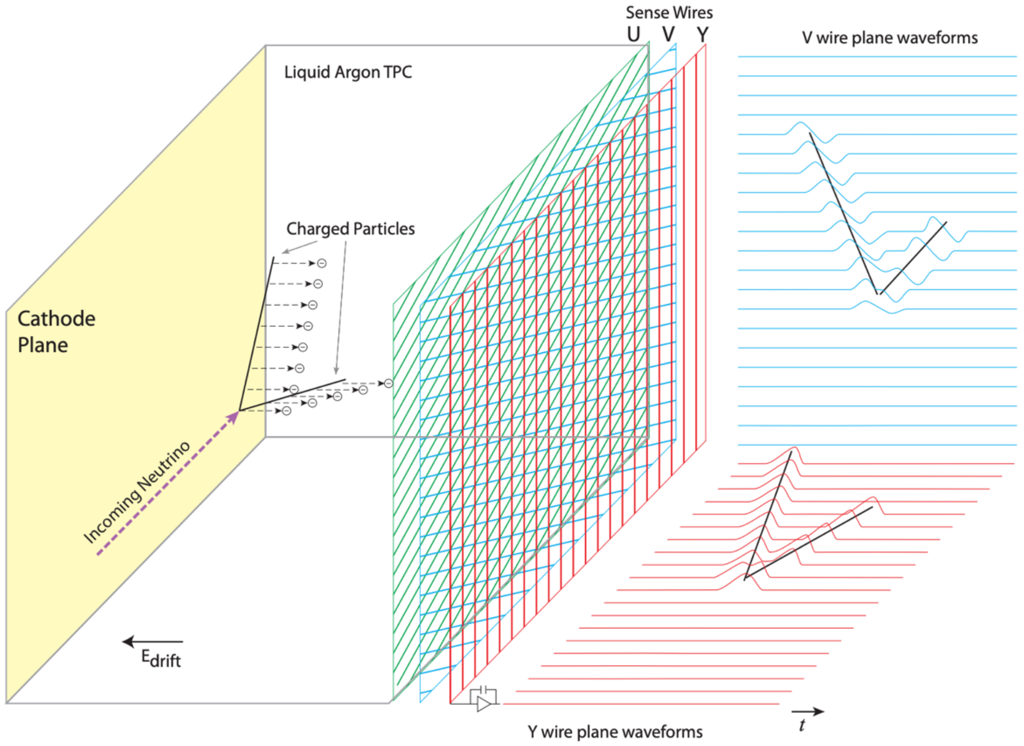
“Light & charge-based” dual phase
Light and charge created in primary interaction
Amplify charge extracted into gas phase
Detect amplified charge at wires/pads

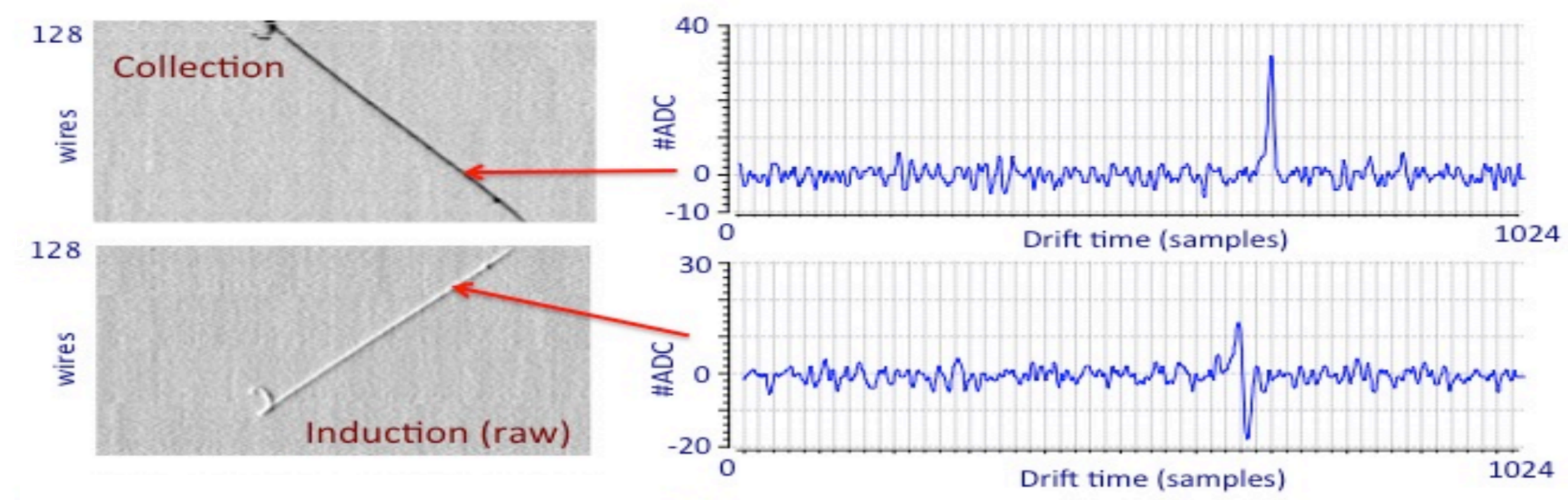






Ionization signal detection





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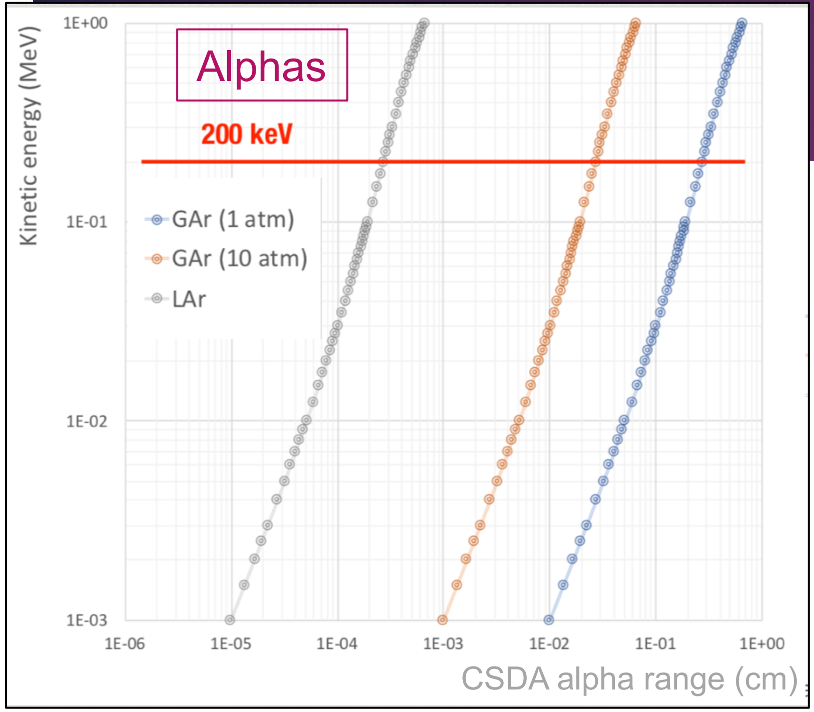
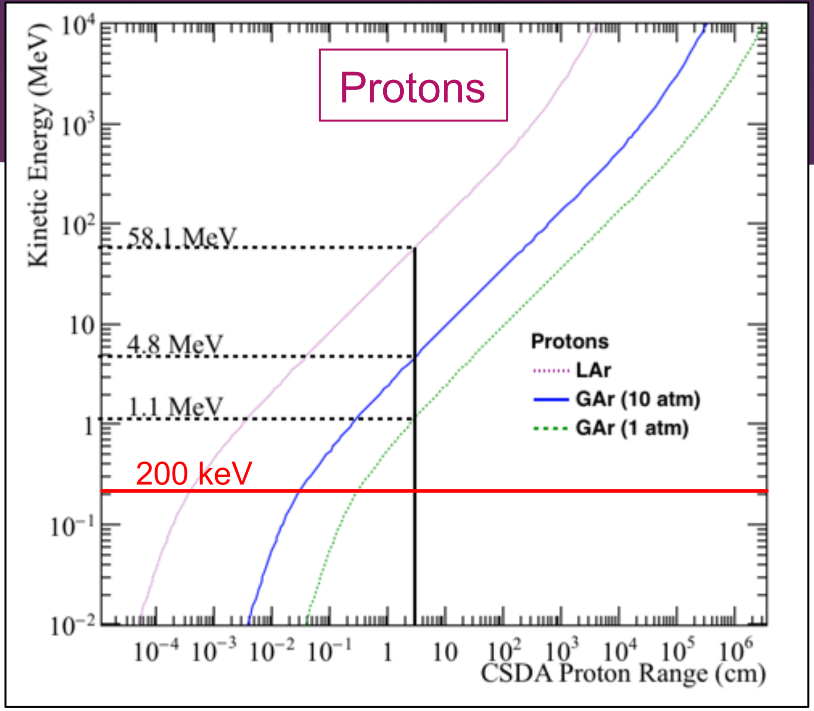
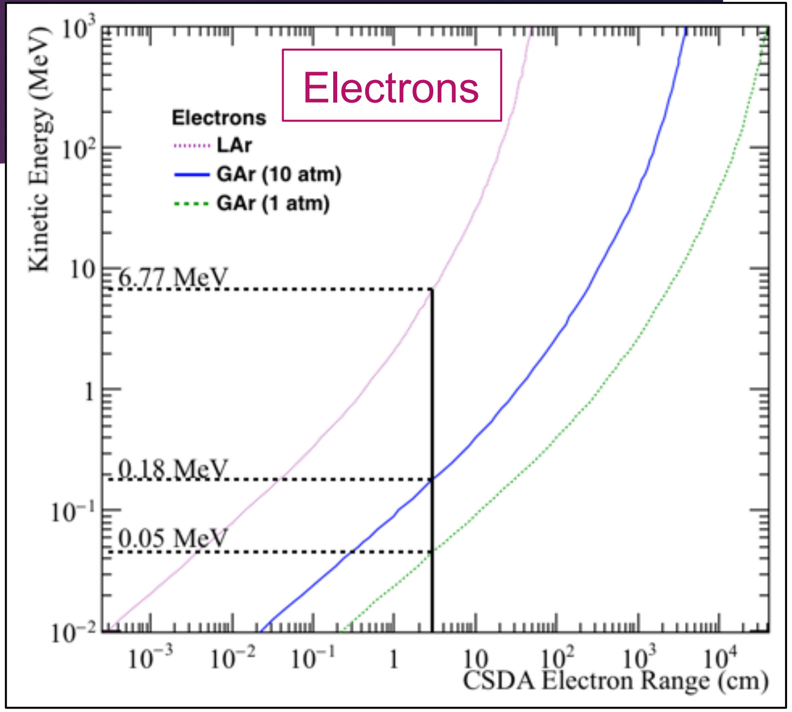
Thresholds: detection → tracking







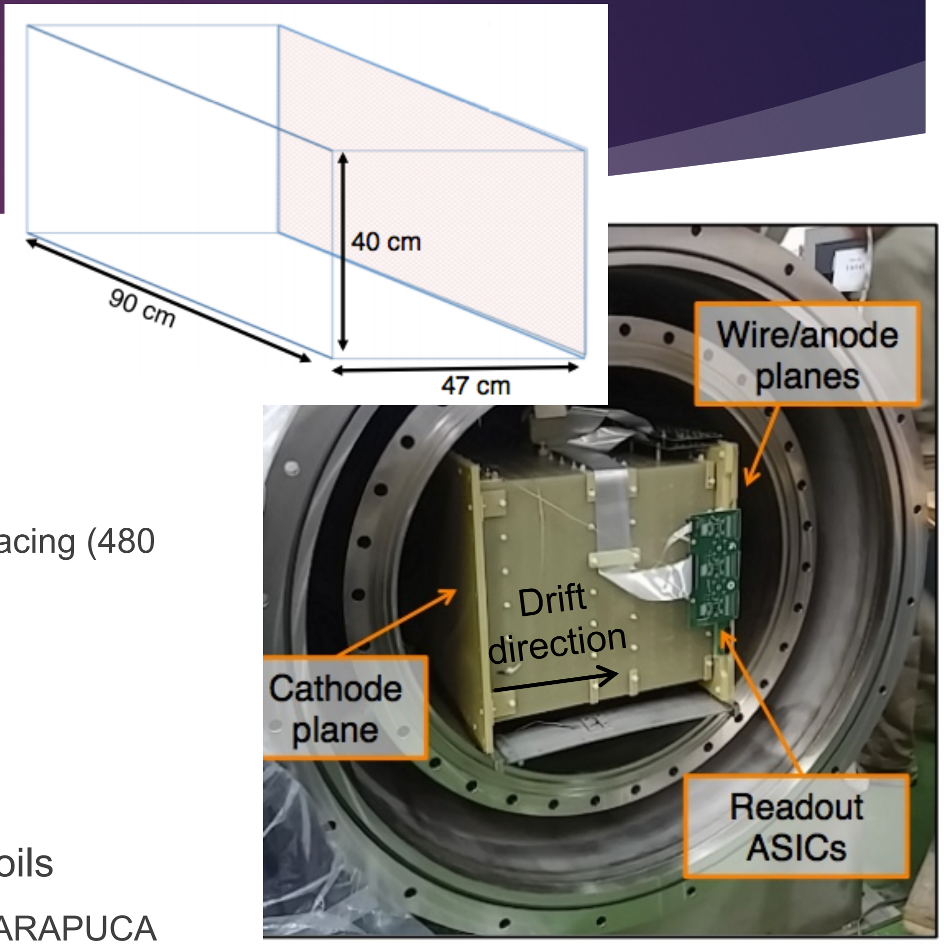
- How low in energy do you need to detect events?
  - If very low energy, scintillation detection is probably better suited than ionization
  - A gaseous TPC could also be considered (with tradeoff in event rate)

Liquid vs. Gas

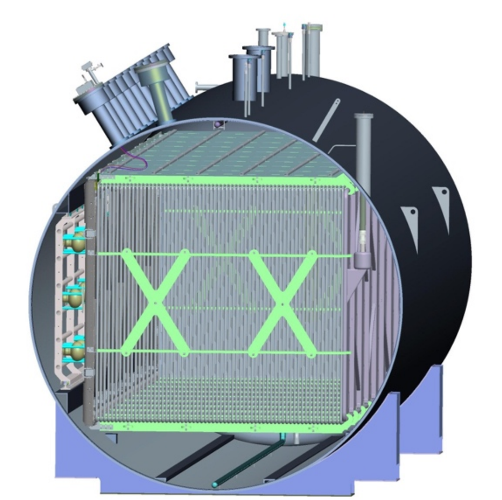
- Drift velocity in LAr at E = ~500 V/cm: 1.6 mm/us
- For a gaseous argon-based TPC, using pure argon is not easy for detector HV stability reasons
  - Usually add O(10%) CH_4 or CO_2, which also has the benefit of increasing drift velocity to ~5-10 **cm**/us
- Spatial resolution
  - Existing 3mm wire pitch LArTPCs achieve ~1mm resolution
  - Existing gaseous TPCs achieve ~100's um resolution
  - Diffusion of drifting electron cloud affects spatial resolution

ArgoNeuT → LArIAT → PixLAr

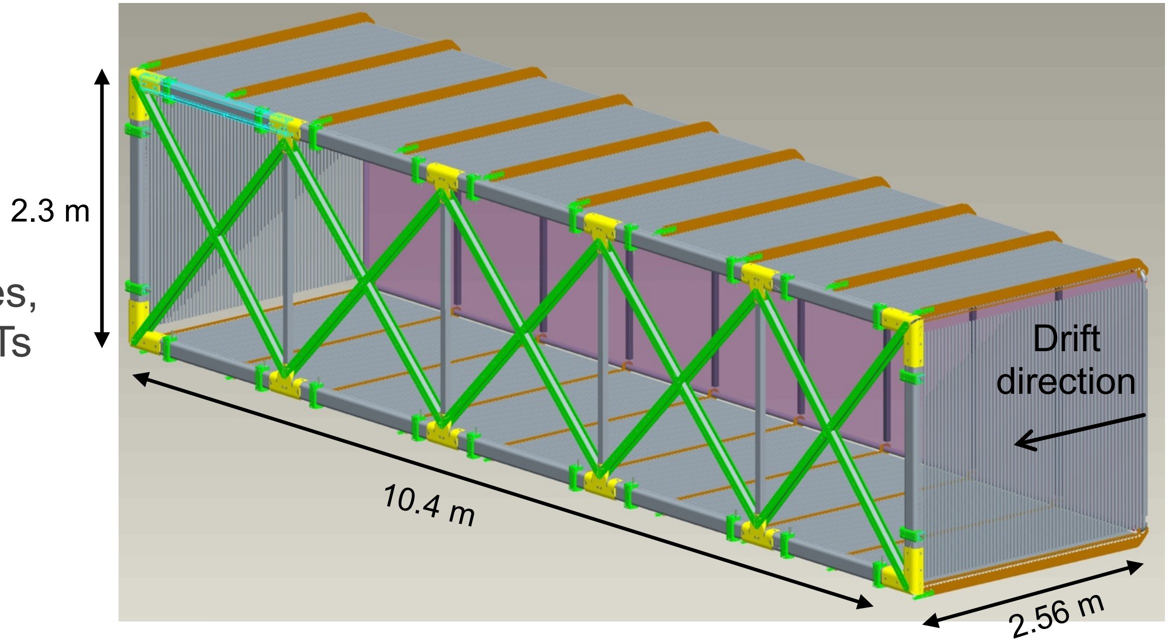
- **TPC**
  - Rectangular TPC with horizontal drift (47 cm, 0.25t active)
  - **ArgoNeuT/LArIAT**: 2 readout wireplanes at ±60° (induction, collection) wireplane (vertical wires, field shaping)
    - **ArgoNeuT**: warm electronics
    - **LArIAT**: BNL + MSU cold electronics, Most data collected with 4mm wire spacing (480 readout channels total), but also collected data w/5mm and 3mm spacing
  - **PixLAr**: 1 plane of rectangular pads
- **Light collection system**
  - **ArgoNeuT**: none
  - **LArIAT/PixLAr**: Interior walls of TPC lined with TPB-coated reflective foils
    - **LArIAT**: 2 cryogenic PMTs view active volume through wireplanes, SiPMs, ARAPUCA prototype
    - **PixLAr**: ARAPUCA, ArcLight prototype, mounted inside field cage



MicroBooNE



- **TPC**
  - Rectangular TPC with horizontal drift (2.56 m, ~89t active)
  - 3 readout wireplanes (2 induction at ±60°, 1 collection w/vertical wires)
  - 3 mm wire pitch (~8200 channels in total)
- **Light collection system**
  - Cryogenic PMTs view active volume through wireplanes, with TPB-coated acrylic plates mounted in front of PMTs



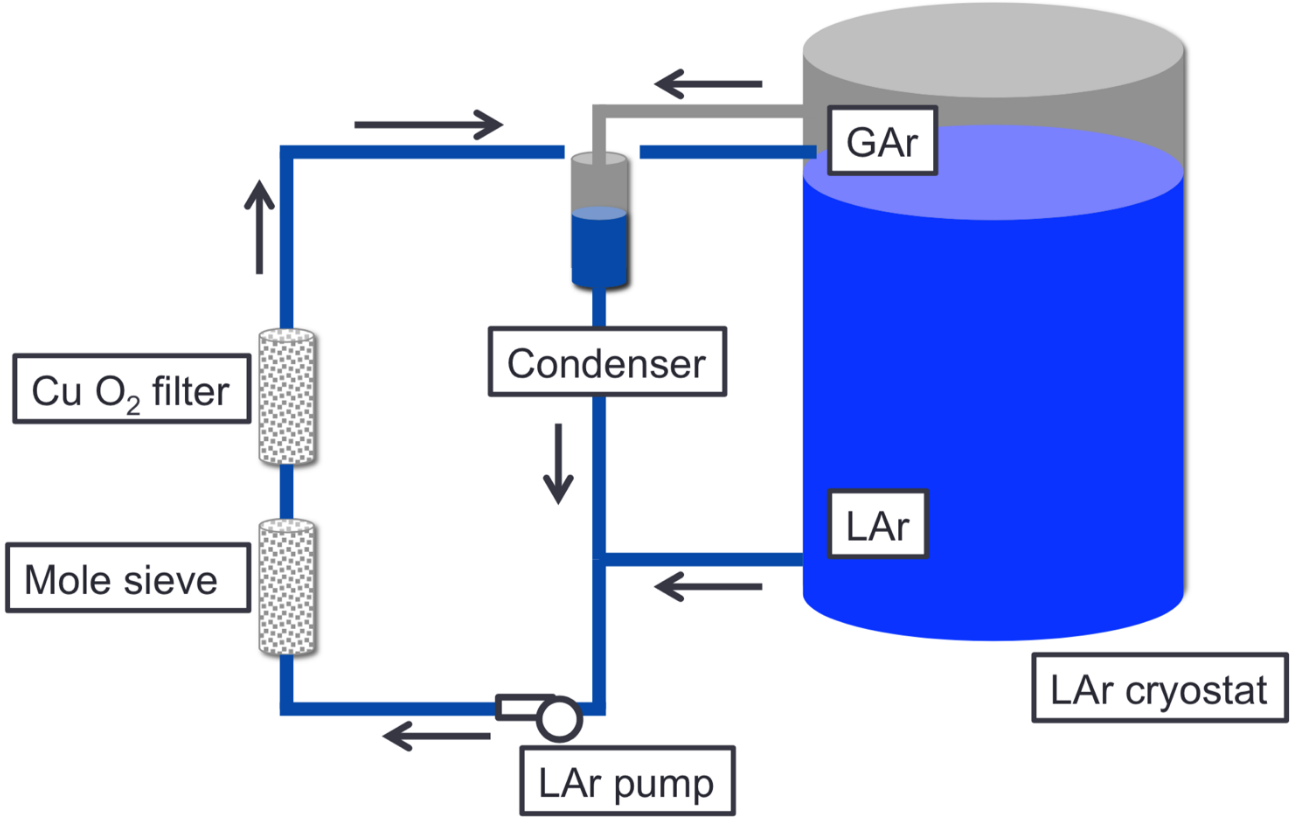
Argon Purity

Parameter	Value	Motivation
Argon purity	<100 ppt O_2	MIP identification at longest drift
Argon purity	<2 ppm N_2	Scintillation light output
LAr Temperature gradient	<0.1 K	Drift-velocity uniformity
LAr recirculation rate	1 volume change/day	Maintain purity
Cryostat heat load	<15 W/m^2	Minimize convection currents and bubbles
Cryogenic capacity	10 kW	Capacity to deal with expected heat load
Cryostat maximum pressure	2.1 bar	Determines relief sizing

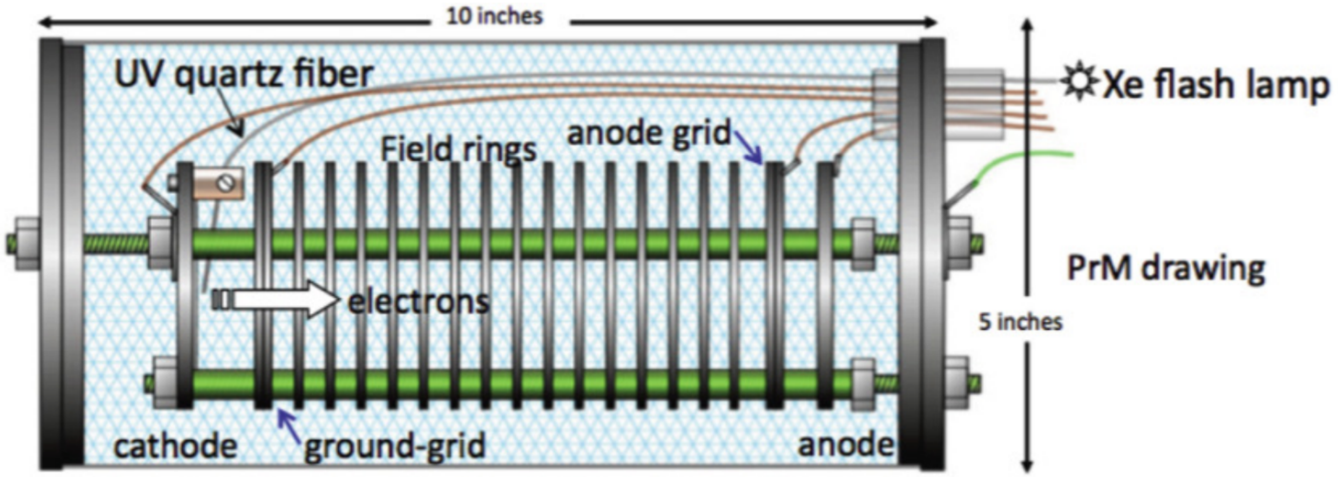
MicroBooNE specs

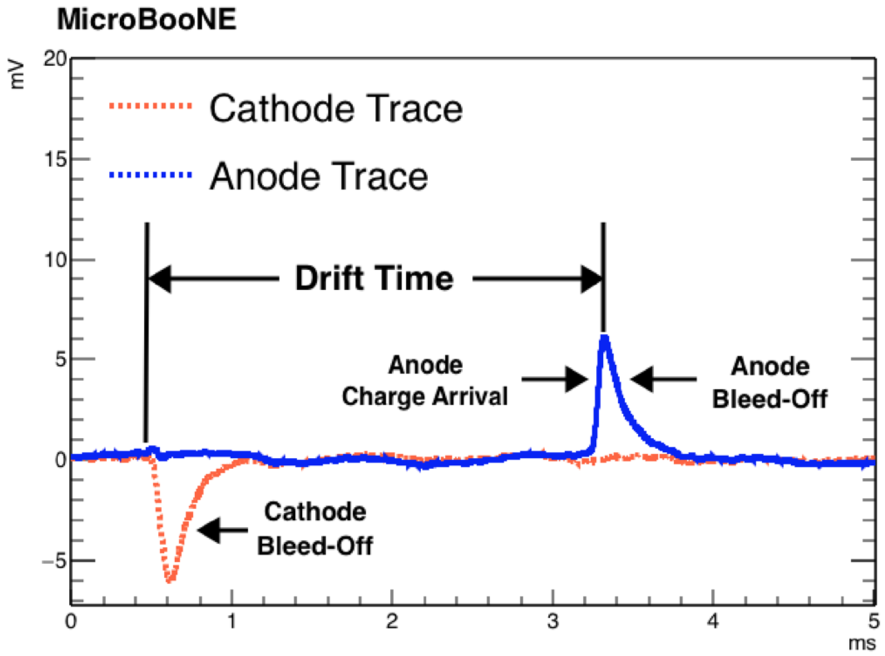
- Longer drift requires more strict requirements on O_2 contamination in the argon
- N_2 requirement does not scale with drift length

Argon Purification Concept



Purity Monitors



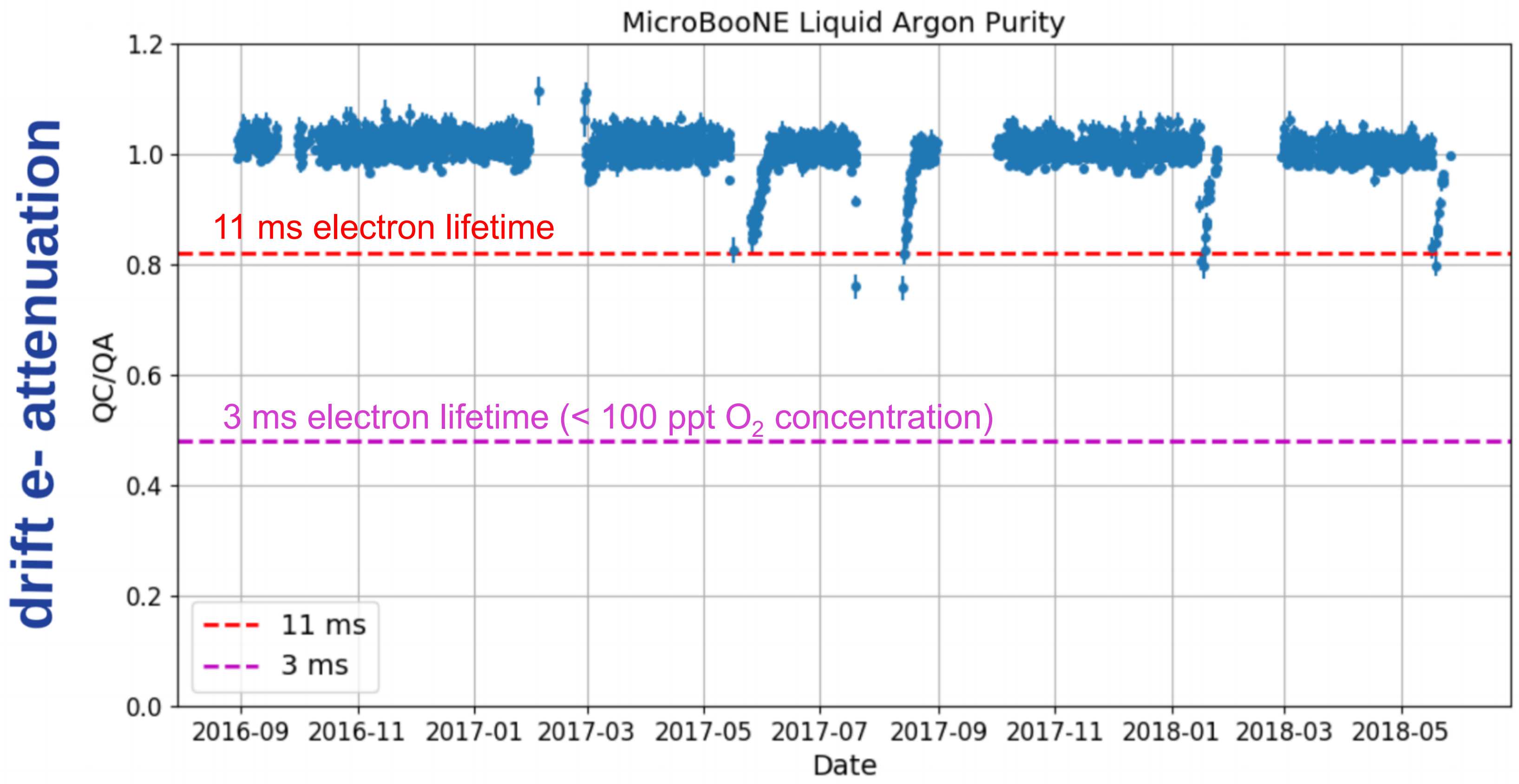


- Ratio of charge at anode and cathode is related to lifetime

$$Q_A/Q_C = e^{-t_{\mathrm{drift}}/\tau}$$

MicroBooNE argon purity

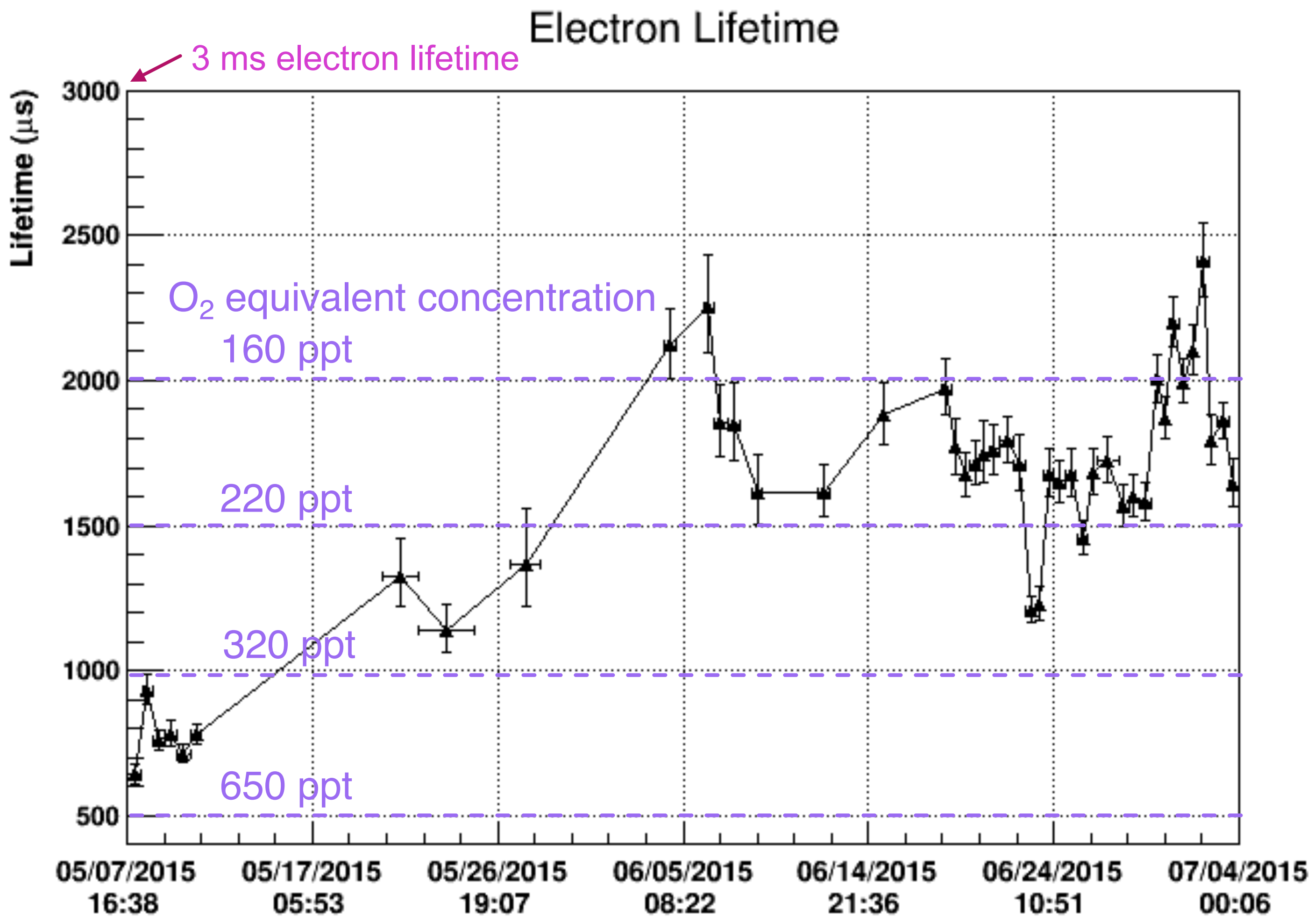
- 2.5m drift length, required at least 3 ms electron lifetime (~100 ppt O_2 concentration)
  - Achieved much higher!



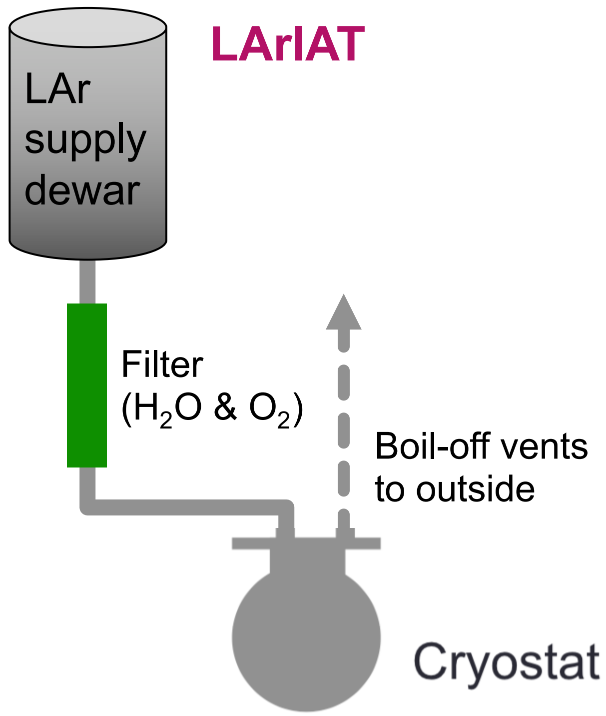
LArIAT argon purity

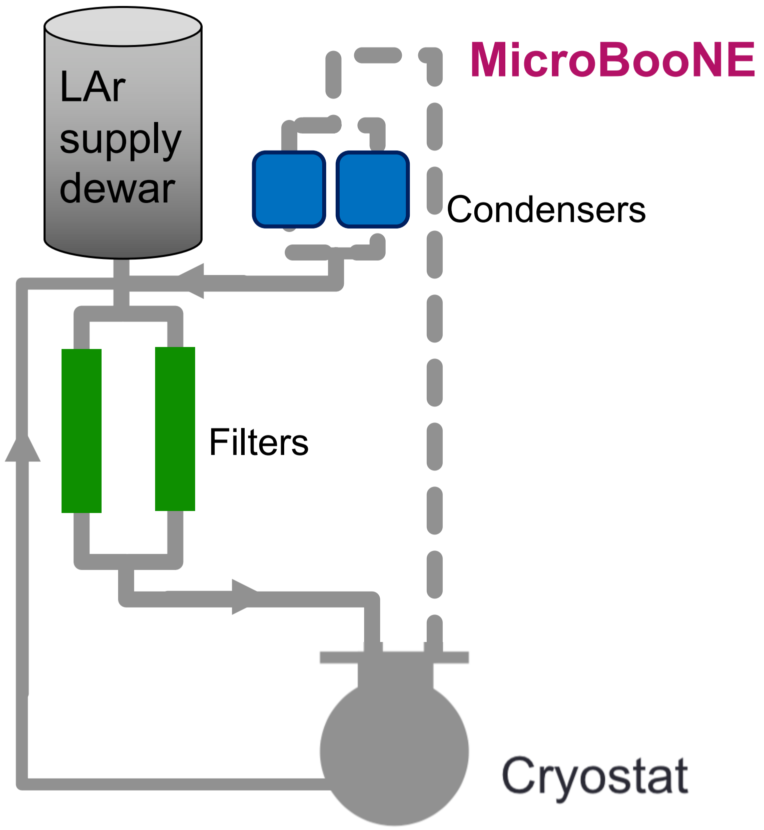
- In contrast, LArIAT was a rollercoaster of O_2-equiv contamination levels…
- But not a huge problem because drift length was so short

"Purity" without LAr recirculation

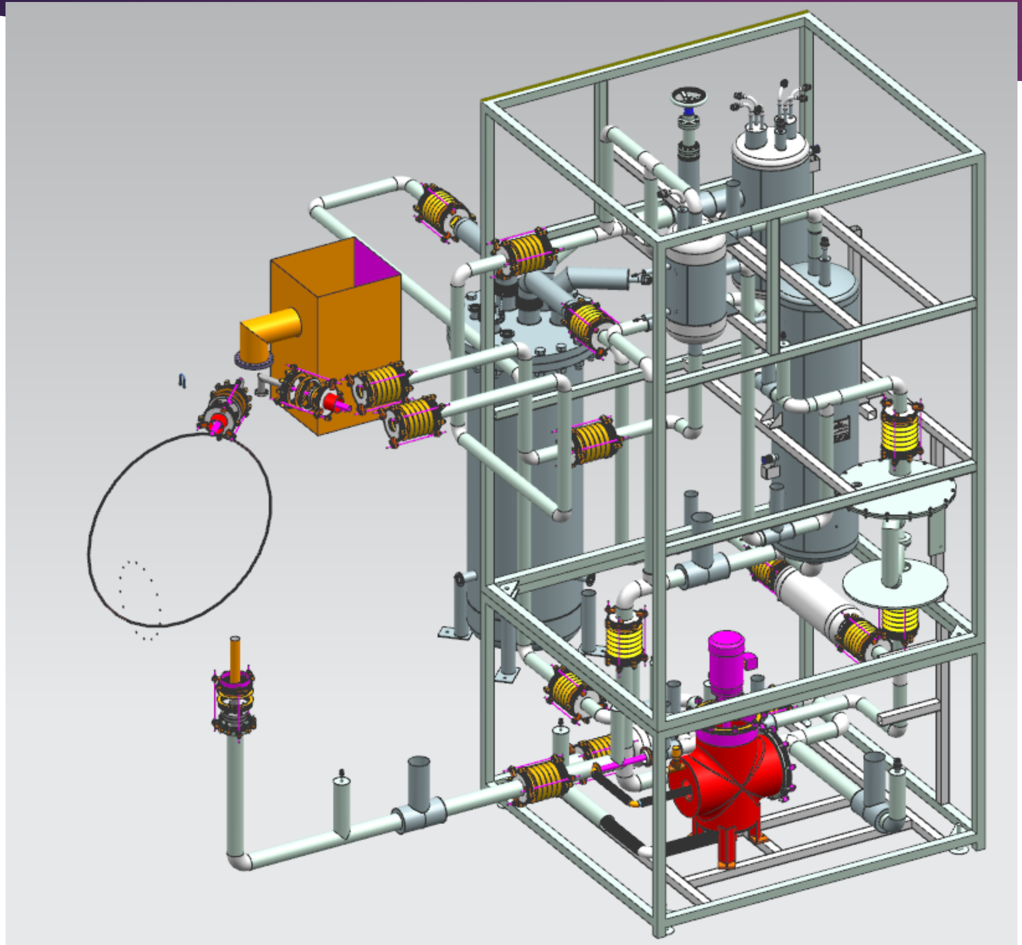


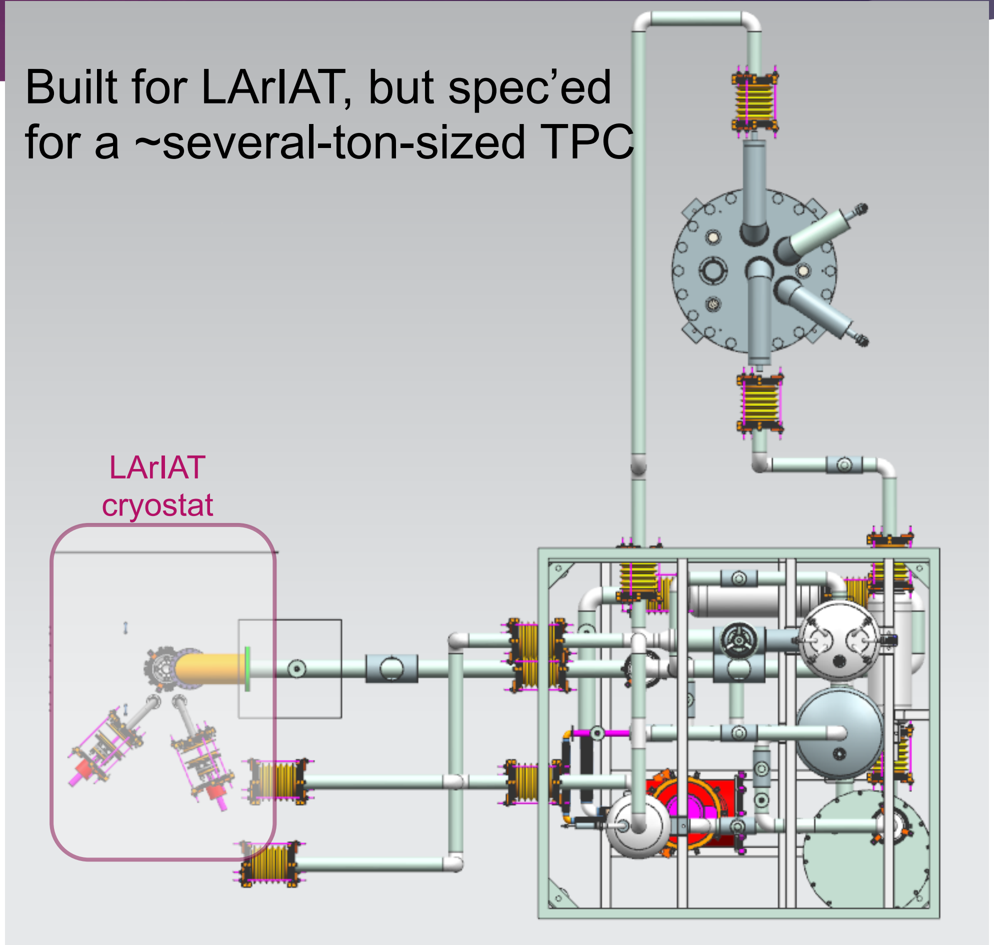
Simplified cryo system comparison





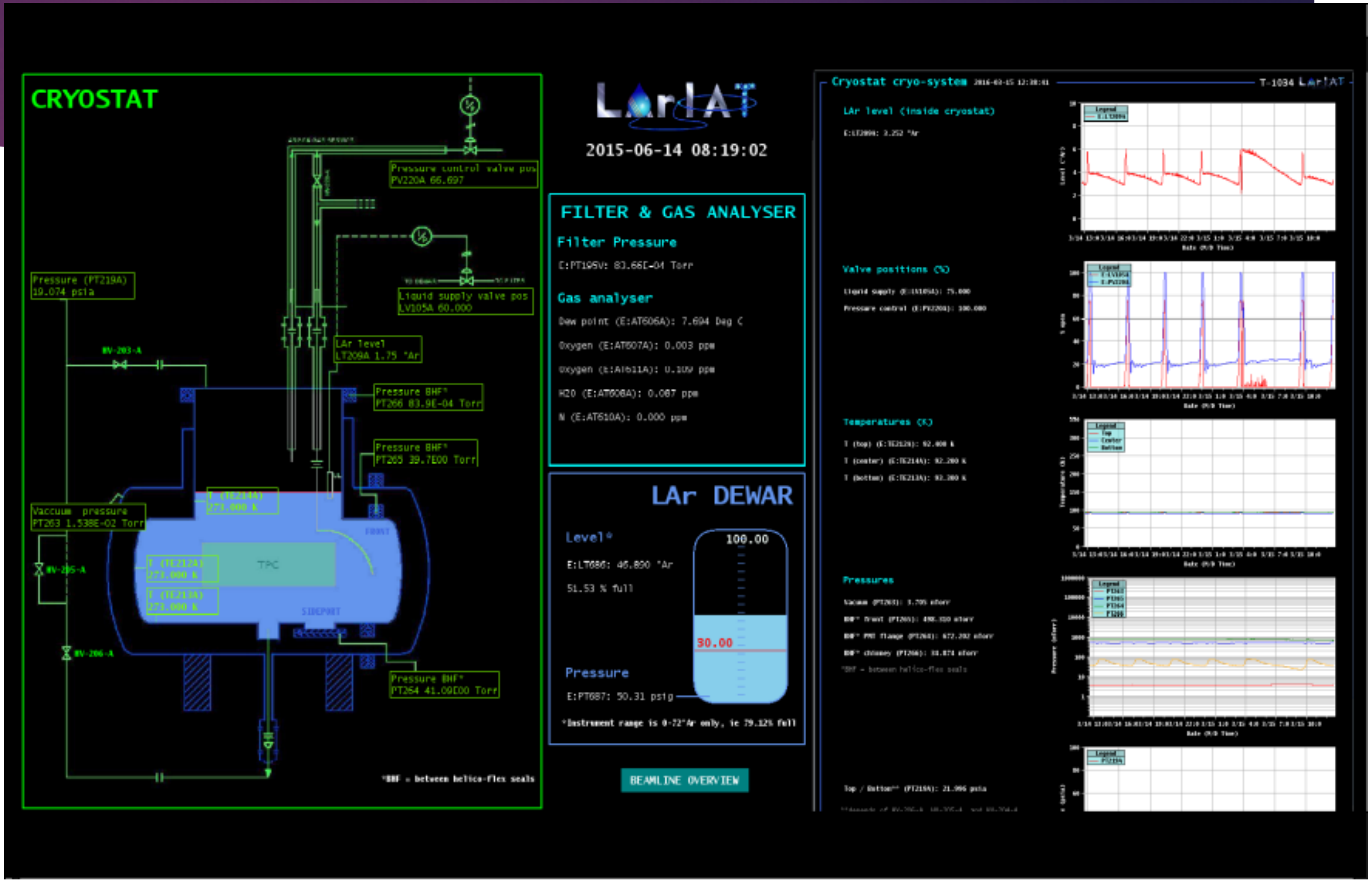
LArIAT's Recirculation/Filtration System (that was never used...)





Infrastructure Needs

- **LAr systems**
  - Cryostat, filters, pumps, condenser, etc.
  - Supply/storage dewars (LN_2, LAr)
  - Monitoring & controls
- **Power**
  - 120V/208V typical for electronics racks, pumps, filters
  - Clean power/Noise isolation
- **Good grounding scheme**



Other things to consider

- **Triggering**
  - If you don't necessarily want to rely on accelerator signals, a light collection system will be needed (trigger on scintillation light to start TPC readout window)
  - External triggers (e.g. for through-going cosmics) are useful for calibrations
  - Would be nice to do streaming data w/offline triggering?
    - E.g., MicroBooNE supernova data stream, uses circular buffer FIFO with external SNEWS alert as delayed trigger
- **TPC size & type**
  - Must balance desired event rate with available space and funding
  - If lower thresholds are desired, gaseous TPC may be a good choice
  - Size sets scale for how good the purification system needs to be
  - Size also sets scale for computing resources needed (e.g., MicroBooNE TPC readout generates ~33 GB/s raw data)

Summary

Considering a LArTPC (or GArTPC) at the STS…

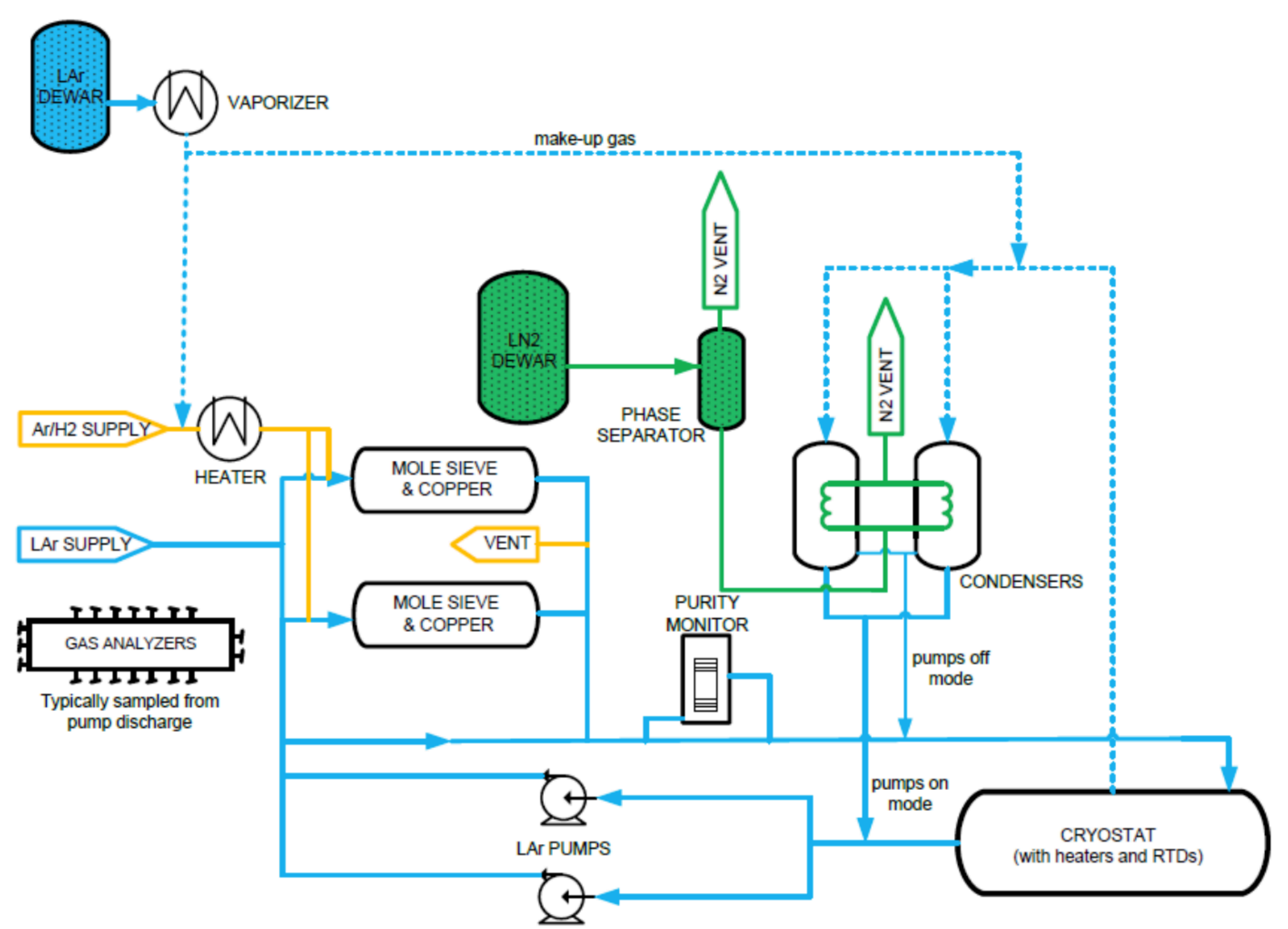
- Need to determine what are the desired thresholds (will it be used for event detection only? Or should it also be able to visualize tracks?) and how many events/year are needed
  - Gaseous TPC would have lower event rates, but would be better at visualizing low energy tracks
- How much space is available, and is that large enough for a TPC + infrastructure?
  - Cryogenic recirculation/purification is critical for larger LArTPCs and lower energy events

Thank you!

Random extra slides…

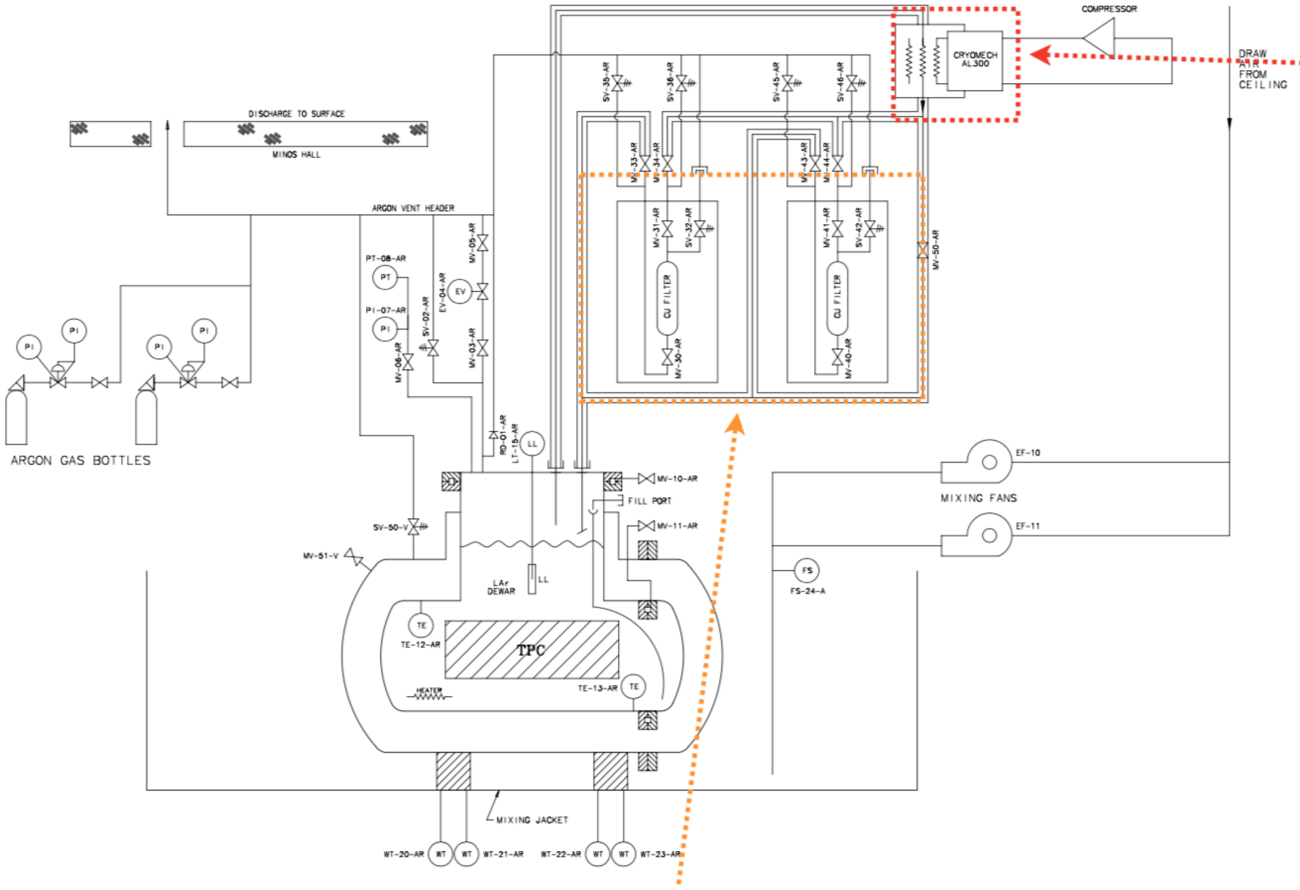
MicroBooNE cryogenic systems

- a



ArgoNeuT cryogenic system

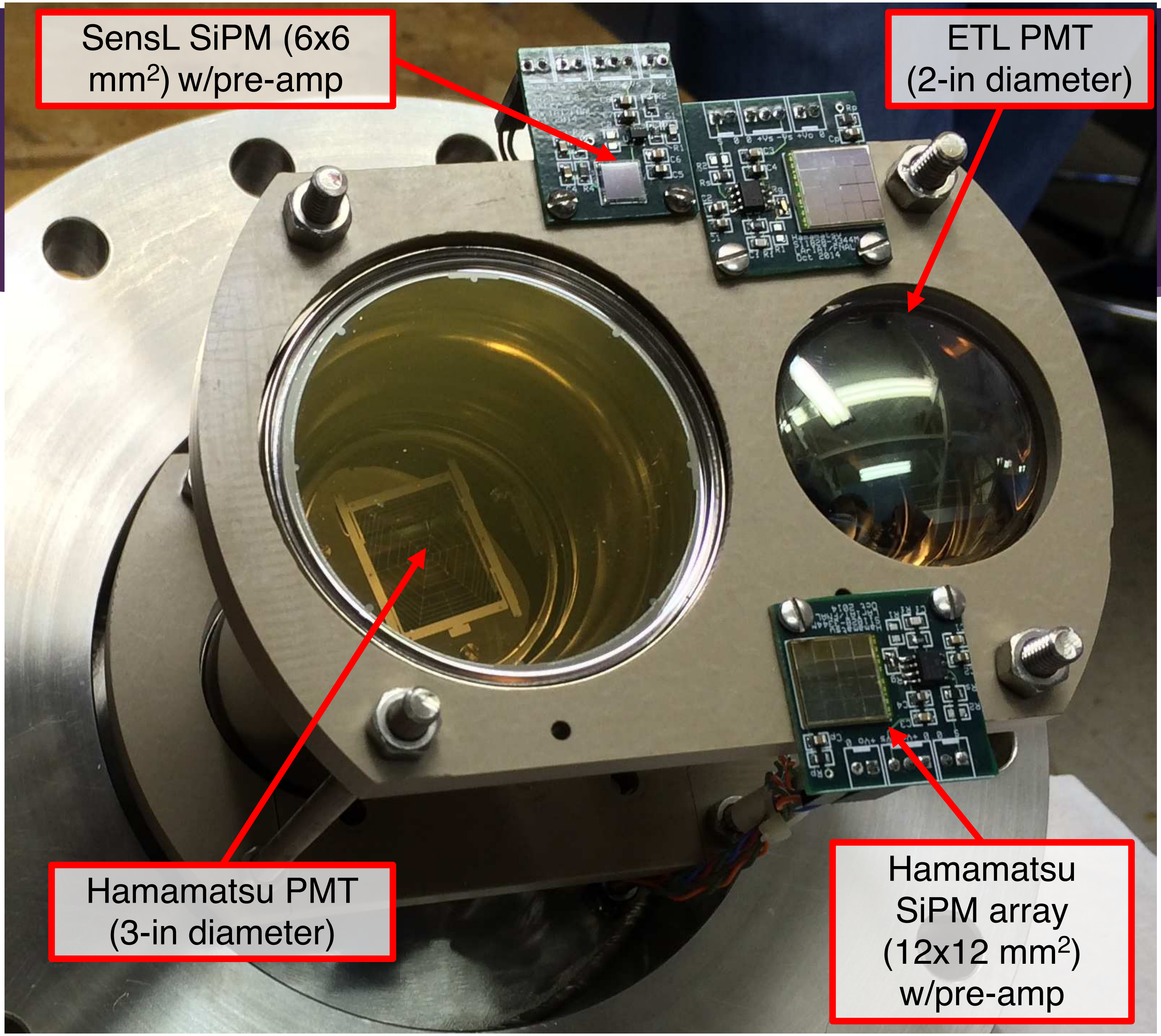
- Simple system with filtration and recirculation



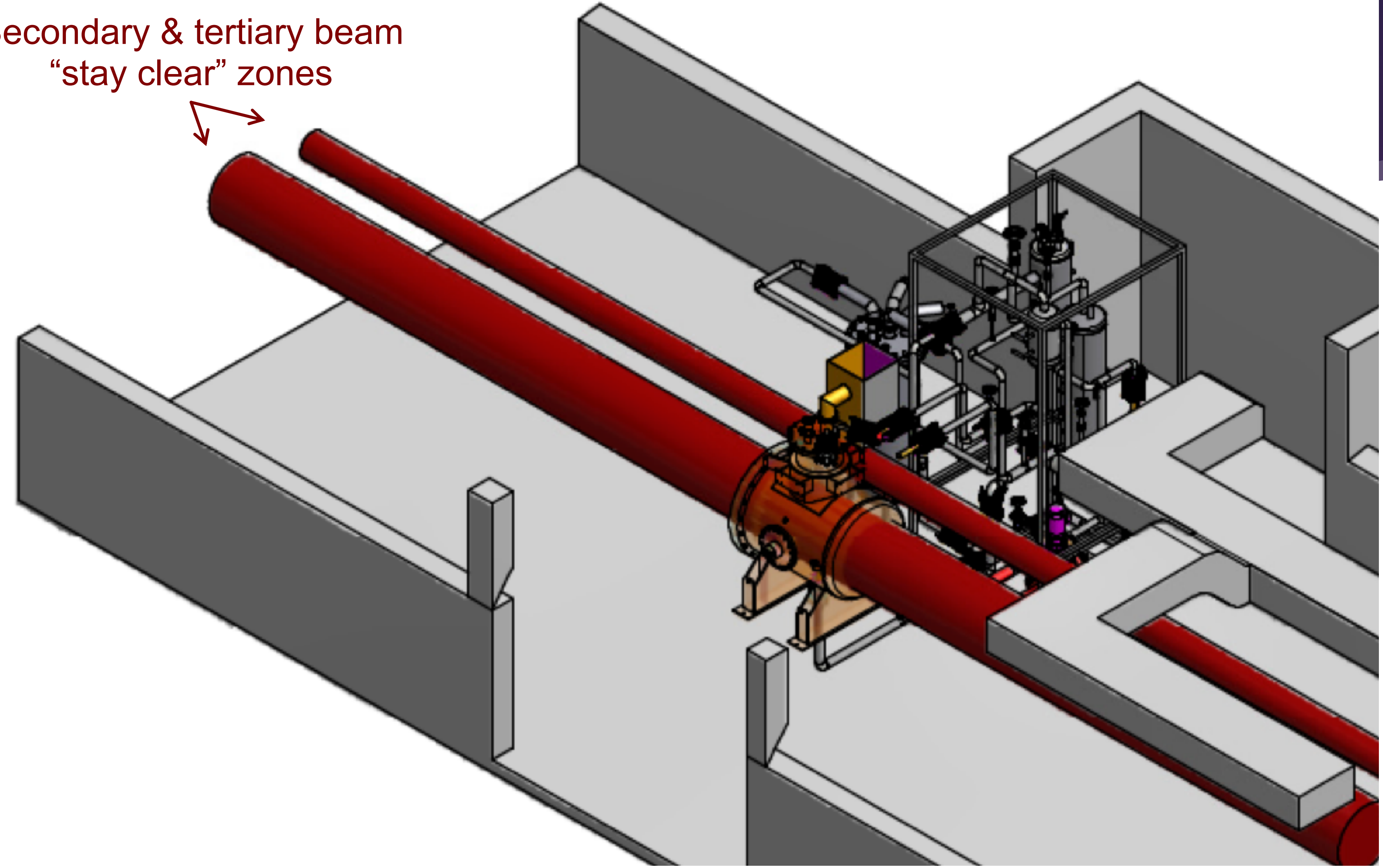
300W cryocooler

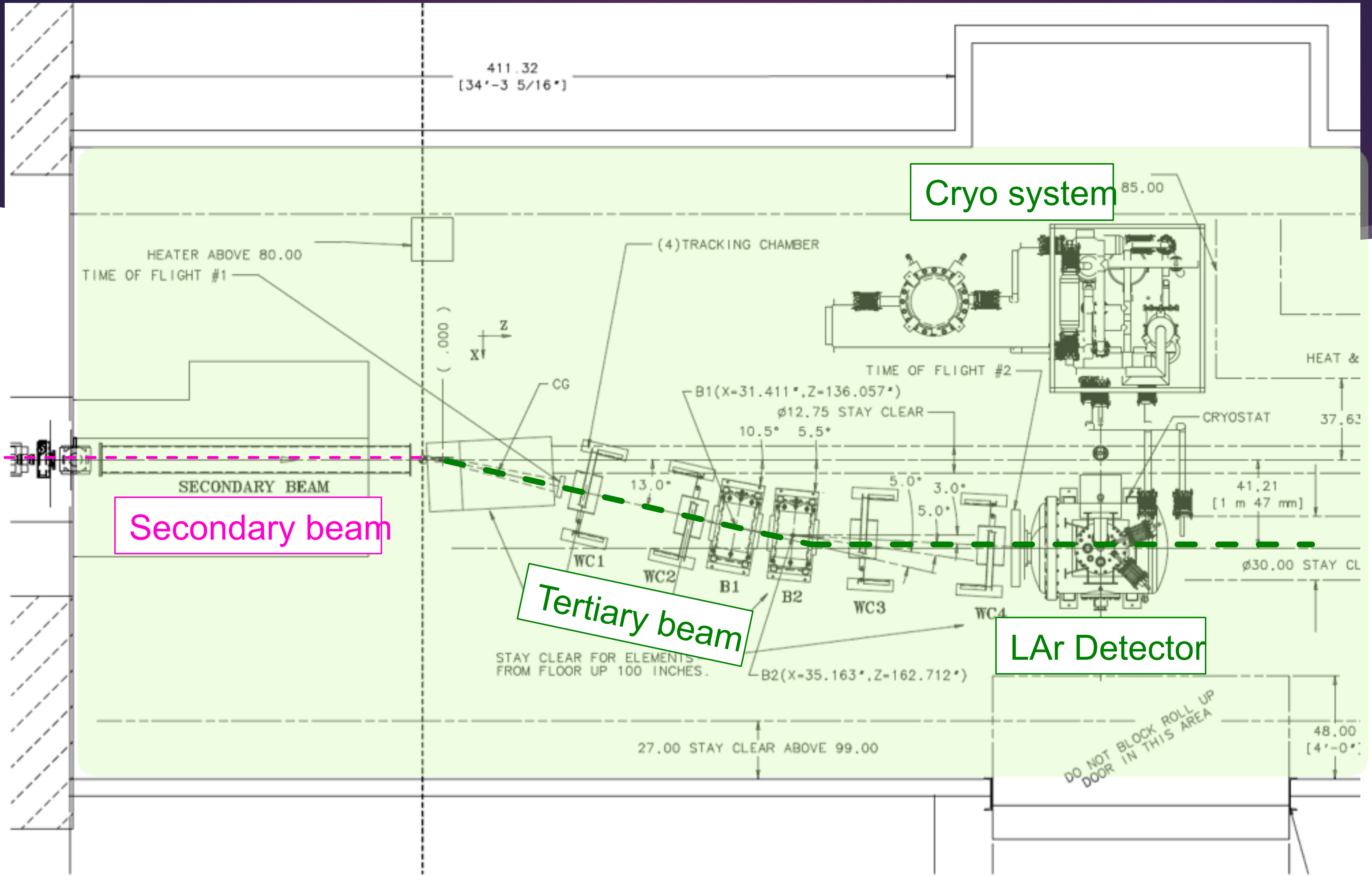
Filters (O_2 and H_2O removal)

- a


SensL SiPM (6x6 mm^2) w/pre-amp
ETL PMT (2-in diameter)
Hamamatsu PMT (3-in diameter)
Hamamatsu SiPM array (12x12 mm^2) w/pre-amp

Secondary & tertiary beam "stay clear" zones





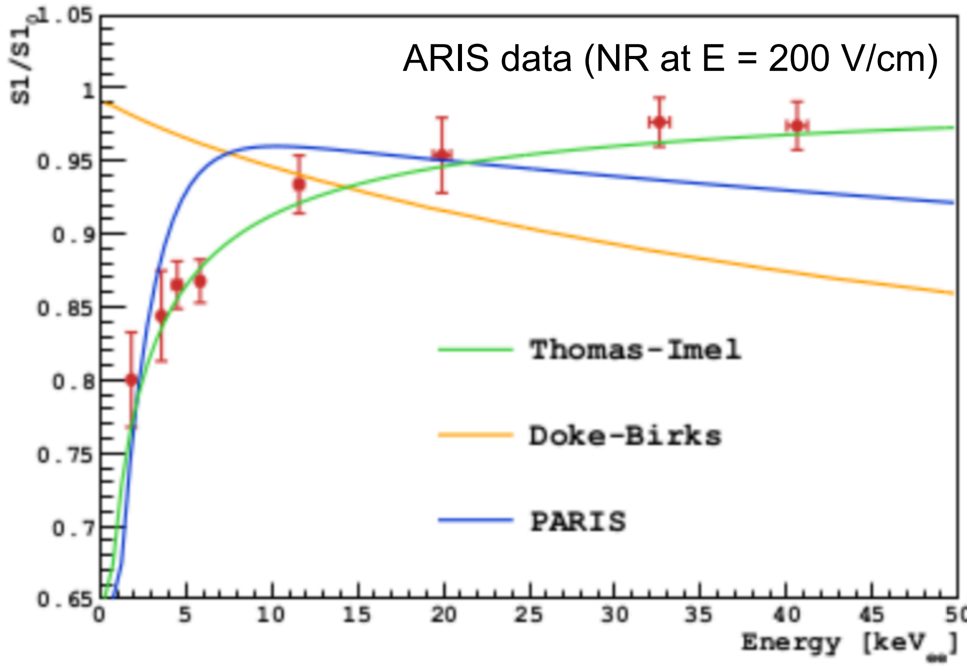
411.32
[34'-3 5/16"]
Cryo system
85.00
HEATER ABOVE 80.00
TIME OF FLIGHT #1
(4)TRACKING CHAMBER
(.000)
Z
X
HEAT &
TIME OF FLIGHT #2
CG
B1(X=31.411",Z=136.057")
Ø12.75 STAY CLEAR
CRYOSTAT
37.63
10.5° 5.5°
13.0°
5.0°
3.0°
5.0°
41.21
[1 m 47 mm]
SECONDARY BEAM
Secondary beam
WC1
WC2
B1
B2
WC3
WC4
Ø30.00 STAY CL
Tertiary beam
LAr Detector
STAY CLEAR FOR ELEMENTS
FROM FLOOR UP 100 INCHES.
B2(X=35.163",Z=162.712")
DO NOT BLOCK ROLL UP
DOOR IN THIS AREA
48.00
[4'-0"]
27.00 STAY CLEAR ABOVE 99.00

Ionization yields

- Number of ionization electrons released by the recoiling nucleus (N_e) depends on:
  - Average excitation/ionization energy (W = 19.5 eV)
  - Relative excitation vs. ionization yield ($\alpha = N_{ex}/N_i$)
  - Ion-electron recombination (R), depends on E field, particle type, argon purity…
  - Nuclear quenching (L_{eff}) (i.e., secondary scattering)

$$N_e = L_{\text{eff}} \frac{E_{\text{dep}}}{W} \frac{1-R}{1+\alpha}$$

- Large uncertainties in recombination models



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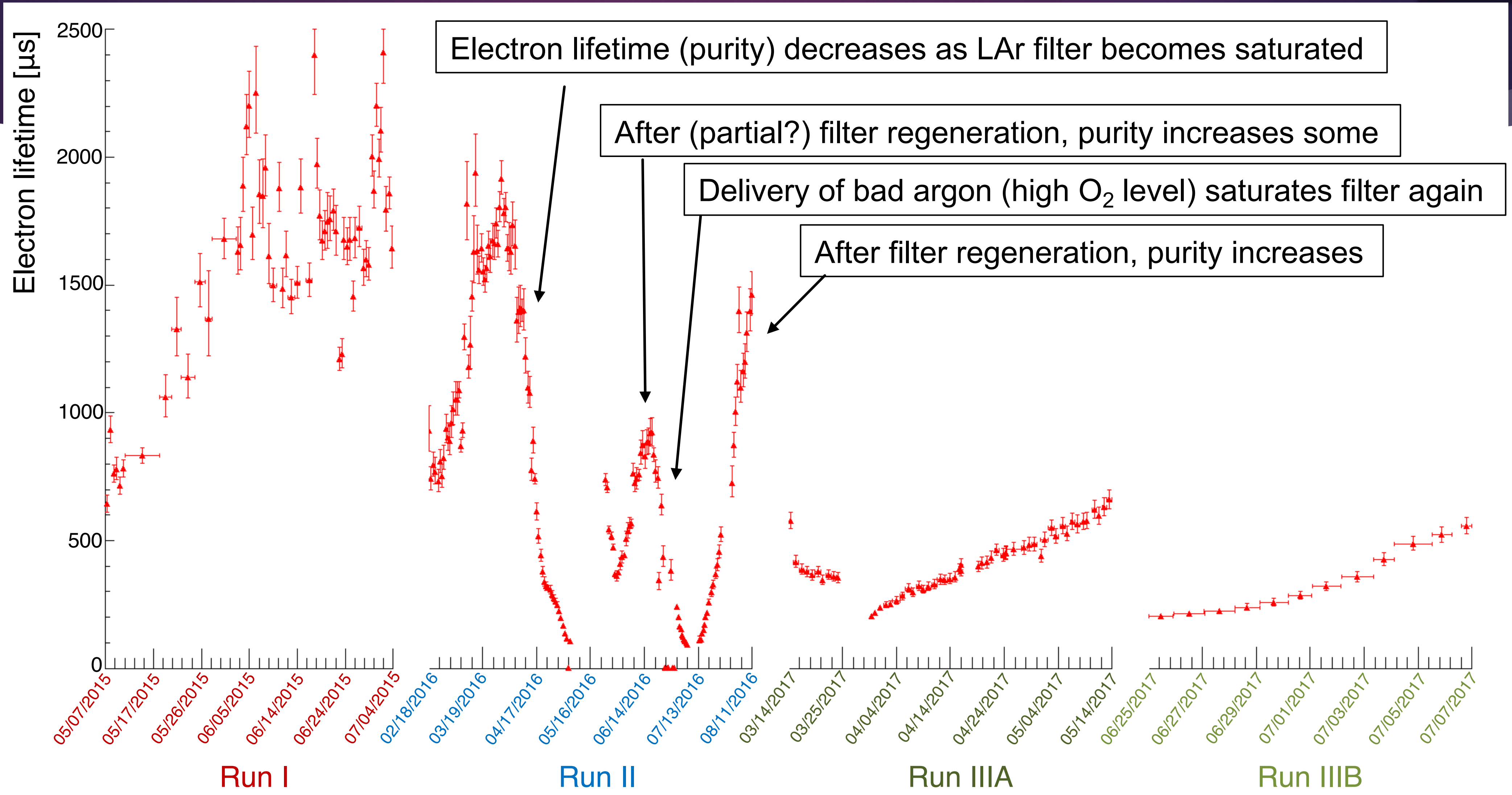
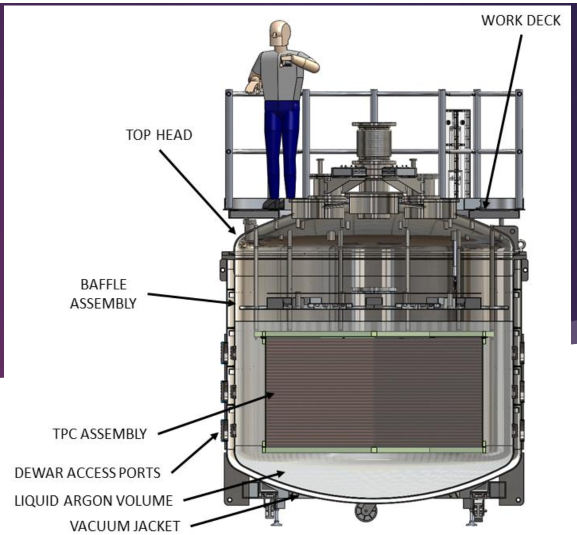
LArIAT



Electron lifetime [µs]
2500
2000
1500
1000
500
0
Electron lifetime (purity) decreases as LAr filter becomes saturated
After (partial?) filter regeneration, purity increases some
Delivery of bad argon (high O2 level) saturates filter again
After filter regeneration, purity increases
05/07/2015
05/17/2015
05/26/2015
06/05/2015
06/14/2015
06/24/2015
07/04/2015
02/18/2016
03/19/2016
04/17/2016
05/16/2016
06/14/2016
07/13/2016
08/11/2016
03/14/2017
03/25/2017
04/04/2017
04/14/2017
04/24/2017
05/04/2017
05/14/2017
06/25/2017
06/27/2017
06/29/2017
07/01/2017
07/03/2017
07/05/2017
07/07/2017
Run I
Run II
Run IIIA
Run IIIB

MiniCAPTAIN/CAPTAIN



- **TPC**
  - Hexagonal TPC with vertical drift
    - MiniCAPTAIN prototype: 32 cm drift, 400 kg active
    - CAPTAIN: 1.0 m drift, 5 tons active volume
  - 5 wireplanes (3 readout + 2 field-shaping/shielding)
  - 3mm wire pitch
    - MiniCAPTAIN 1000 channels
    - CAPTAIN: 2000 channels
- **Light collection system**
  - Cryogenic PMTs view active volume through TPB-coated windows in cathode plane